MSC Nastran Topology Optimization - Minimizing mass with stress and displacement constraints

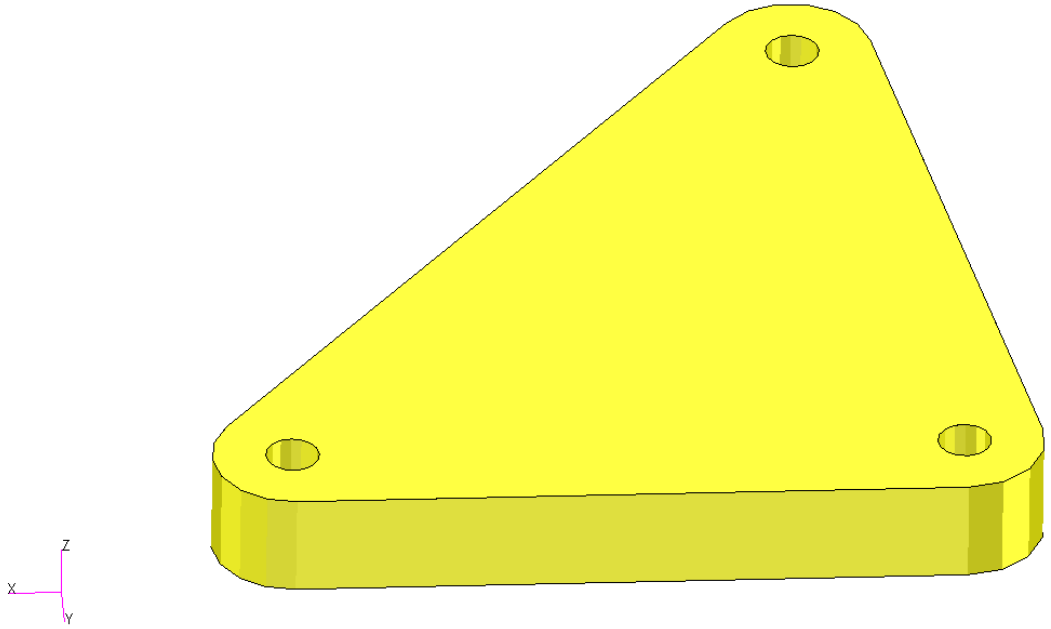
PRESENTED BY CHRISTIAN APARICIO

Questions? Email: christian@ the-engineering-lab.com

Goal: Use Nastran SOL 200 Optimization

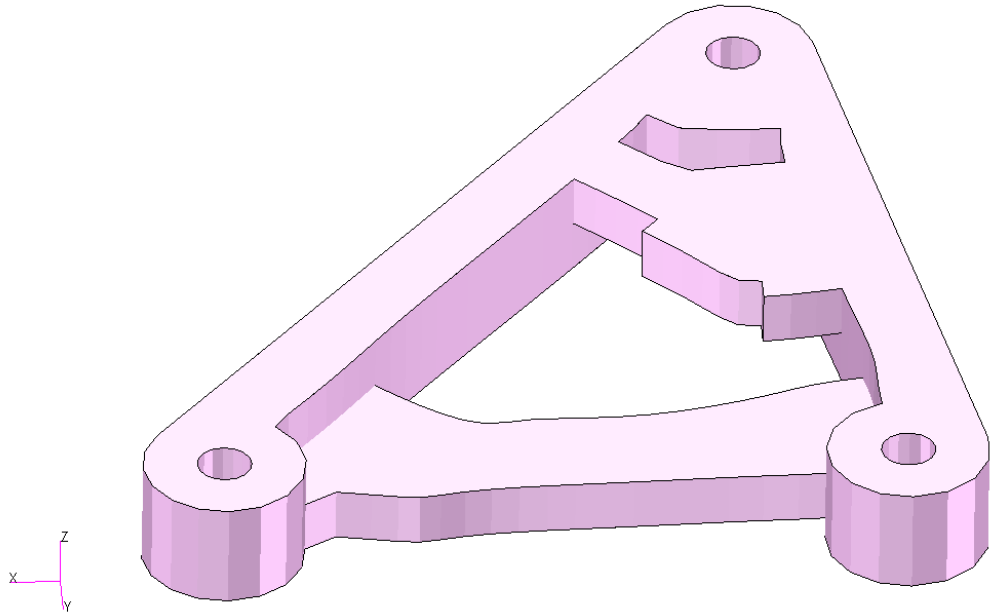
Before Optimization

- Mass: 18 kg

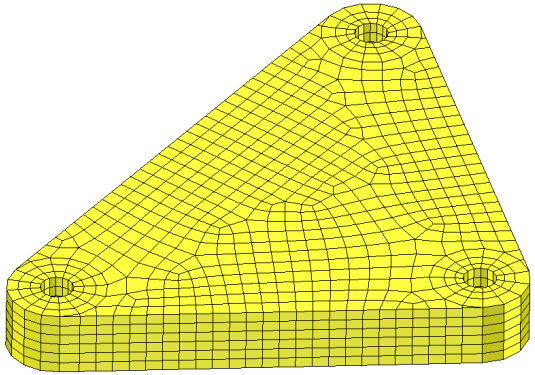


After Optimization

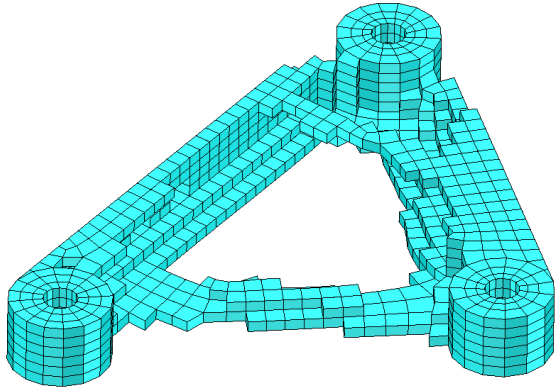
- Mass: 9.3 kg
- Prevent excessive stress and displacements



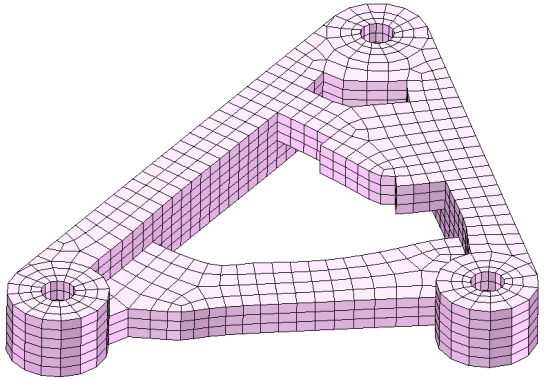
Goal: Use Nastran SOL 200 Optimization



1) Initial Design



2) Proposed Topology Solution



3) Final Design

Agenda

Details of the structural model

Optimization Problem Statement

Steps to use Nastran SOL 200 (Optimization)

- Convert a .bdf file to SOL 200
- Create:
  - Design Regions/Variables
  - Design Objective
  - Design Constraints
- Perform optimization with Nastran SOL 200

View optimization results

- Online Plotter
- Topology Optimization and Structural Results

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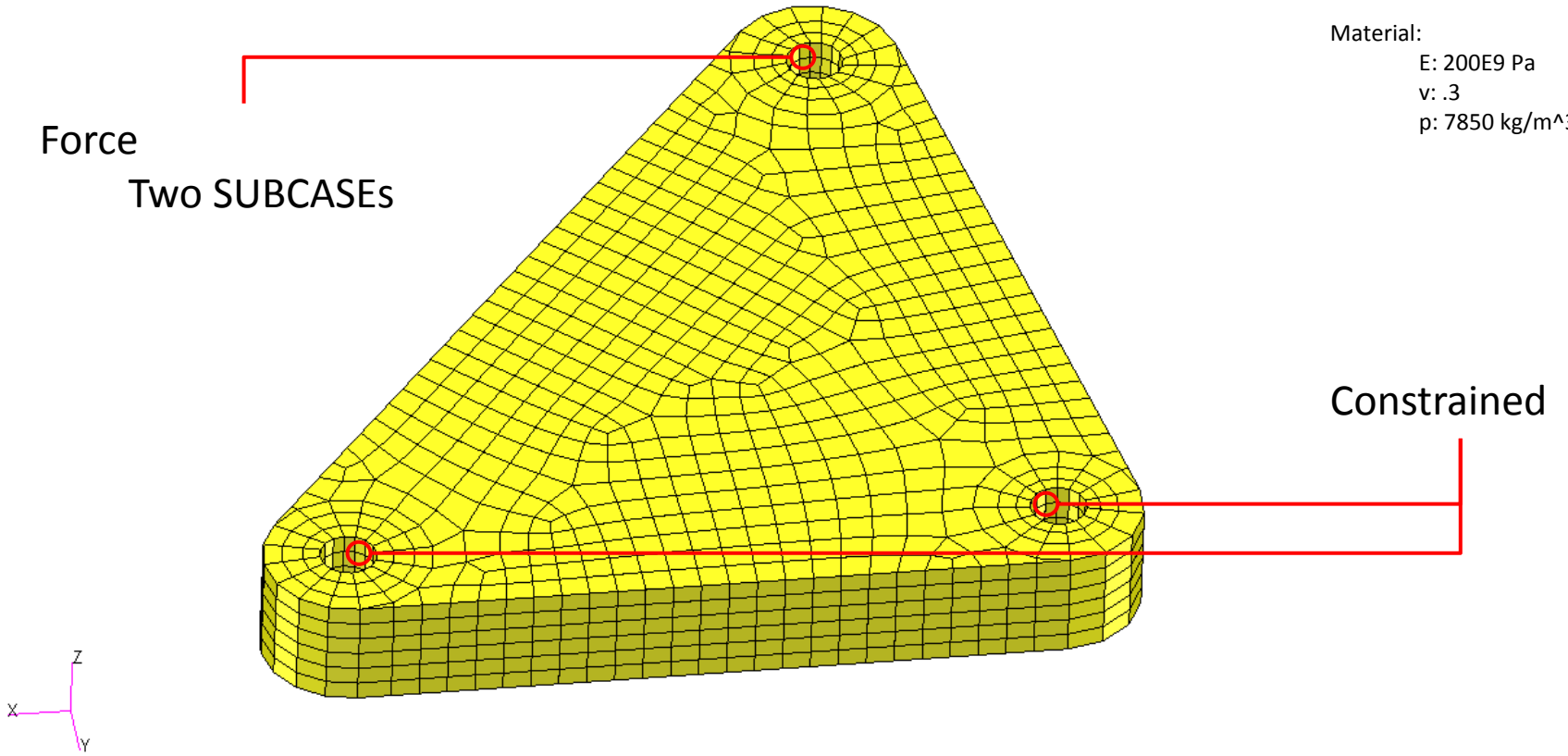
Details of the structural model

Units: m, N, MPa

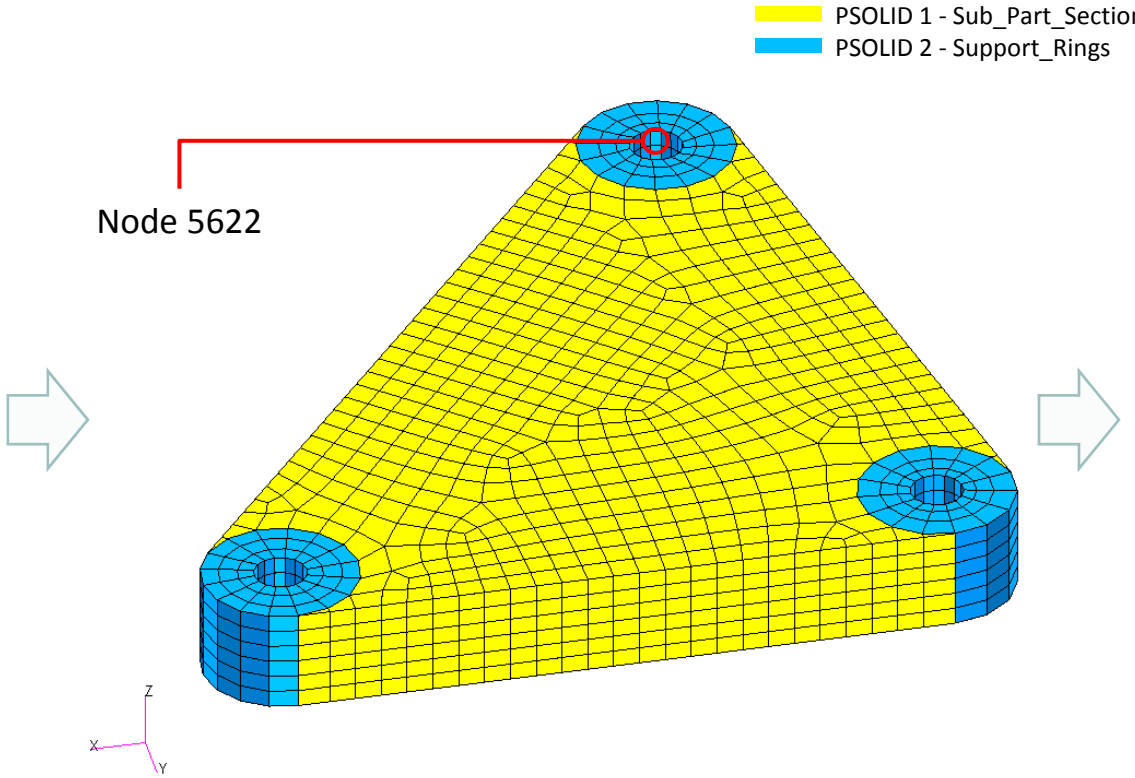
Material:
E: 200E9 Pa
v: .3
p: 7850 kg/m^3



Optimization Problem Statement

Design Region/Variables

x1: PSOLID 1



Design Objective

r0: Minimize fractional mass (FRMASS)

Design Constraints

r1: Z displacement at node 5622 (GRID 5622)

r1 < .0008 m

x1: Maximum allowable stress, 2.0E8 Pa, on design region x1

Steps to use Nastran SOL 200 (Optimization)

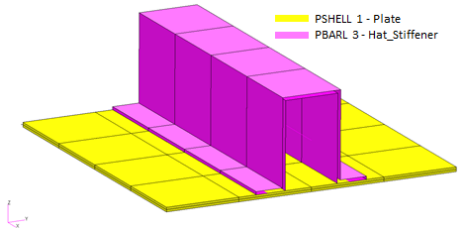
1. Start with a .bdf or .dat file
2. Use the SOL 200 Web App to:
   - Convert the .bdf file to SOL 200
     - Design Regions/Variables
     - Design Objective
     - Design Constraints
   - Perform optimization with Nastran SOL 200
3. Review optimization results
   - Online Plotter
   - Topology Optimization and Structural Results

SOL 200 Web App Capabilities

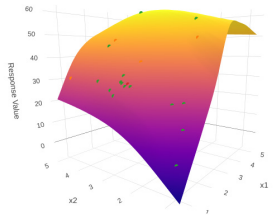
Benefits

- 200+ error validations (real time)
- Web browser accessible
- Automated creation of entries (real time)
- Automatic post-processing
- 76 tutorials

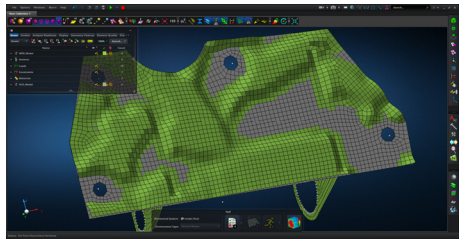
Capabilities



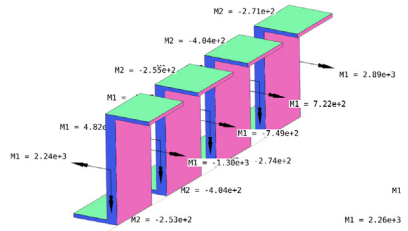
Web Apps for SOL 200
Pre/post for MSC Nastran SOL 200. Support for size, topology, topometry, topography and multi-model.



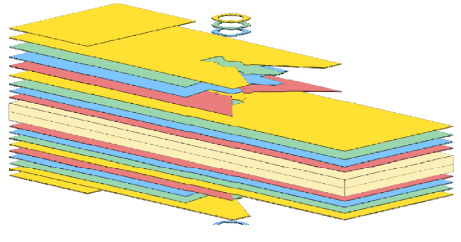
Machine Learning Web App
Bayesian Optimization for nonlinear response optimization (SOL 400)



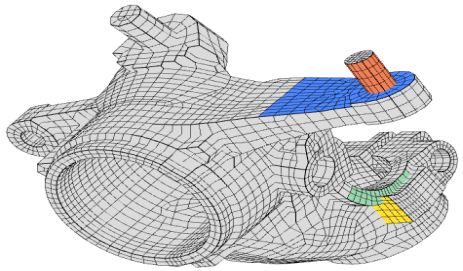
MSC Apex Post Processing Support
View the newly optimized model after an optimization



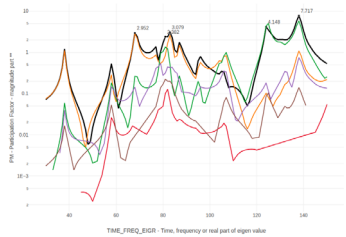
Beams Viewer Web App
Post process 1D element forces, including shear forces, moments, torque and axial forces



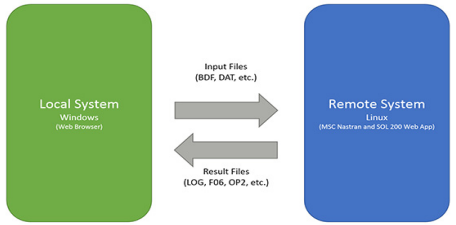
Ply Shape Optimization Web App
Spread plies optimally and generate new PCOMPG entries



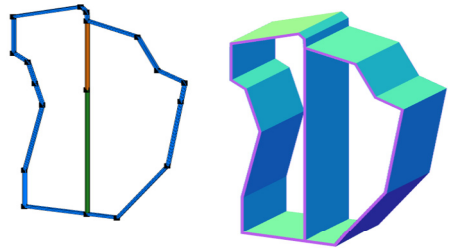
Shape Optimization Web App
Use a web application to configure and perform shape optimization.



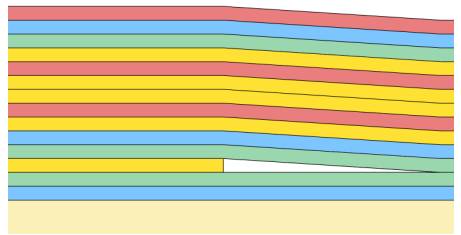
HDF5 Explorer Web App
Create XY plots using data from the H5 file



Remote Execution Web App
Run MSC Nastran jobs on remote Linux or Windows systems available on the local network



PBMSECT Web App
Generate PBMSECT and PBRSECT entries graphically



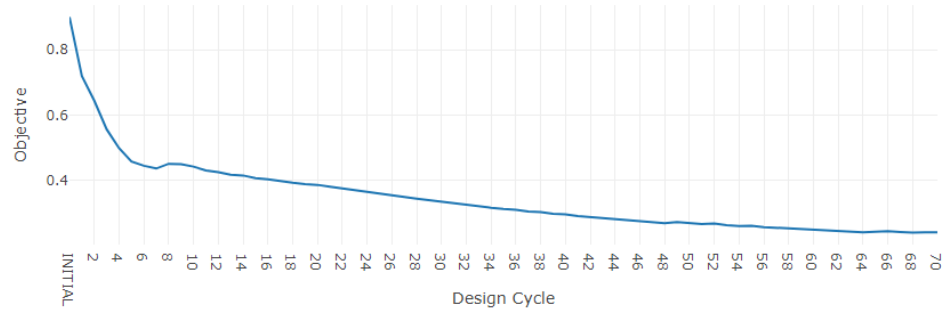
Stacking Sequence Web App
Optimize the stacking sequence of composite laminate plies

View Optimization Results
Online Plotter

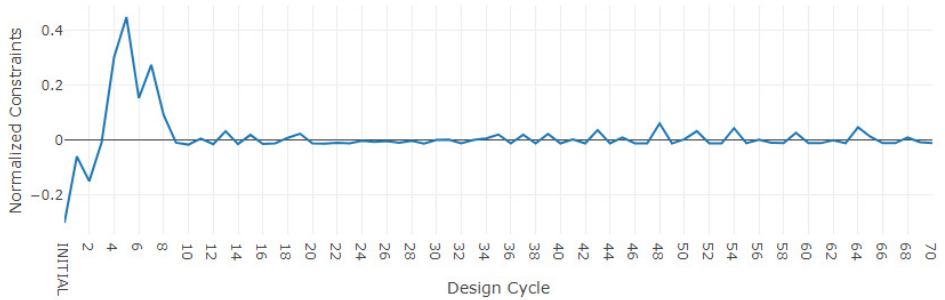
Final Message in .f06

RUN TERMINATED DUE TO HARD CONVERGENCE TO AN OPTIMUM AT CYCLE NUMBER = 70.

Objective



Normalized Constraints



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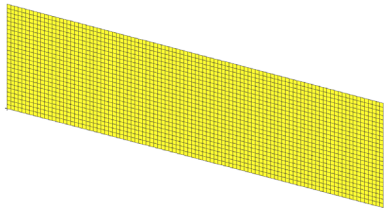
Topology Optimization Workflows

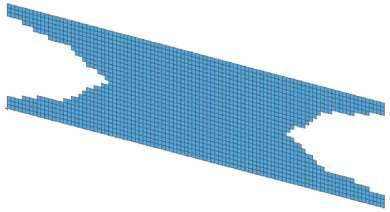
Traditional Topology Optimization

Objective: Minimize Compliance (Maximize Stiffness)
Constraint: Fractional Mass < .## (Target Mass)

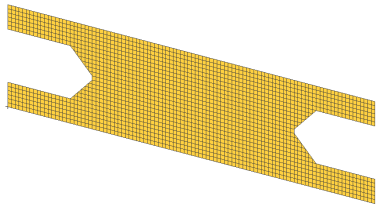
Original Design



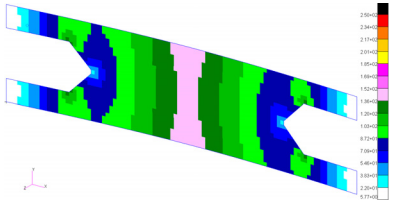
Mass: 9.737 grams



FRMASS < .75
Mass: 7.186 g
Optimization B



Mass: 7.739 g



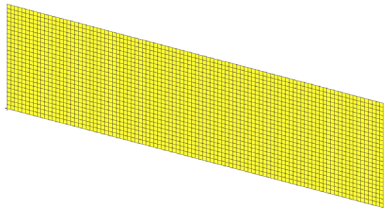
Max von Misses: 150 MPa
Max Displacement : 2.78 mm

1st natural Frequency: 111 Hz

Traditional Topology Optimization

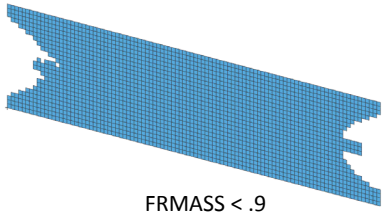
Objective: Minimize Compliance (Maximize Stiffness)
Constraint: Fractional Mass < .## (Target Mass)

Original Design

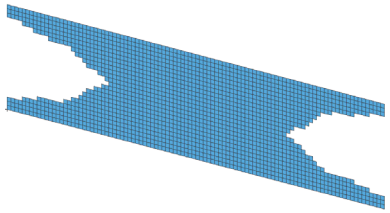


Mass: 9.737 grams

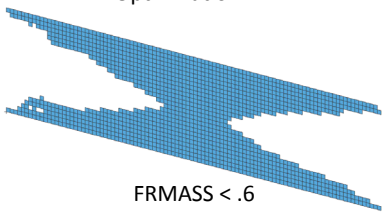
Topology Solution



FRMASS < .9
Mass: 8.756 g
Optimization A

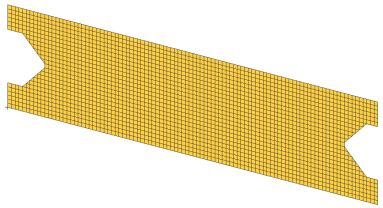


FRMASS < .75
Mass: 7.186 g
Optimization B

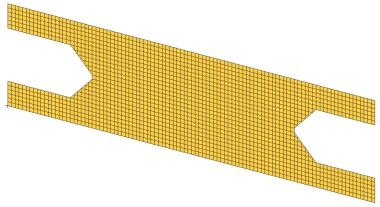


FRMASS < .6
Mass: 5.718 g
Optimization C

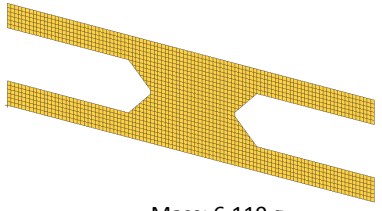
Refined Design



Mass: 9.094 g

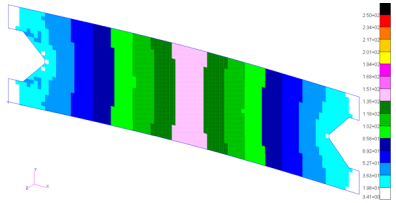


Mass: 7.739 g



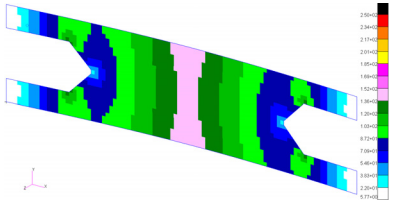
Mass: 6.119 g

Verification



Max von Misses: 150 MPa
Max Displacement: 2.52 mm

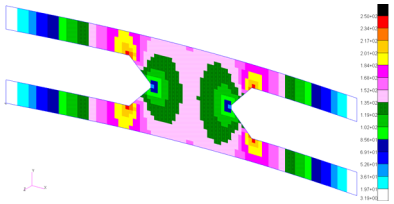
1st natural Frequency: 114 Hz



Max von Misses: 150 MPa
Max Displacement : 2.78 mm

1st natural Frequency: 111 Hz

Optimization B led to a valid and light weight design



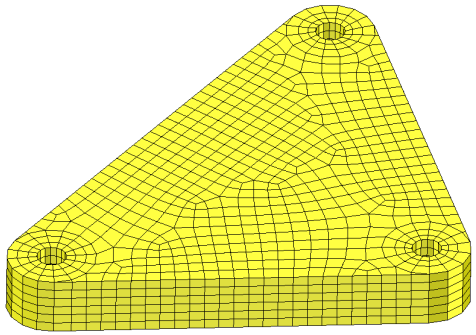
Max von Misses: 250 MPa
Max Displacement : 3.57 mm

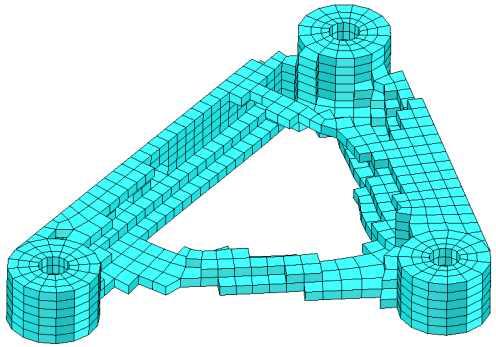
1st natural Frequency: 109 Hz

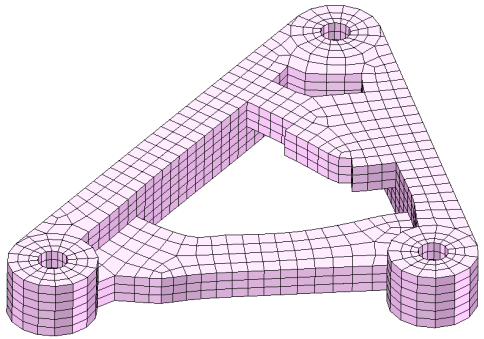
Latest Topology Optimization

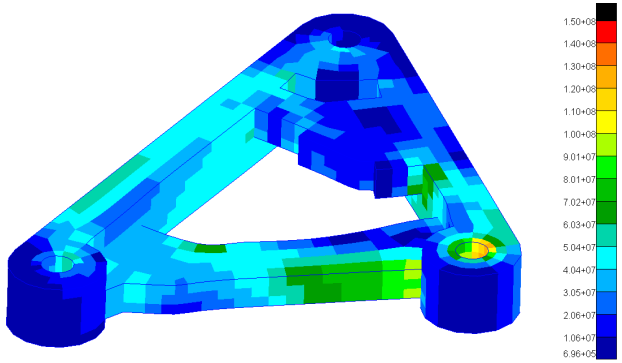
Objective: Minimize Fractional Mass (Minimize Mass)
Constraint: Stress Constraint

Original Design → Topology Solution → Refined Design → Verification









Appendix

What is FRMASS or Fractional Mass?

- At the start of the optimization, the INITIAL design has its material densities reduced.
- During the optimization, each normalized material density is varied in order to minimize the compliance of the entire structure (increase the stiffness)
- IMPORTANT: Always use decimal points when specifying FRMASS

Total: 6

1.0	1.0	1.0
1.0	1.0	1.0

1) INITIAL design
- FRMASS = 1.0
- Original density

Total: 1.8

.3	.3	.3
.3	.3	.3

2) Reduction (Start of Optimization)
- FRMASS = .3
- All densities are set to .3 (30%) of the original density

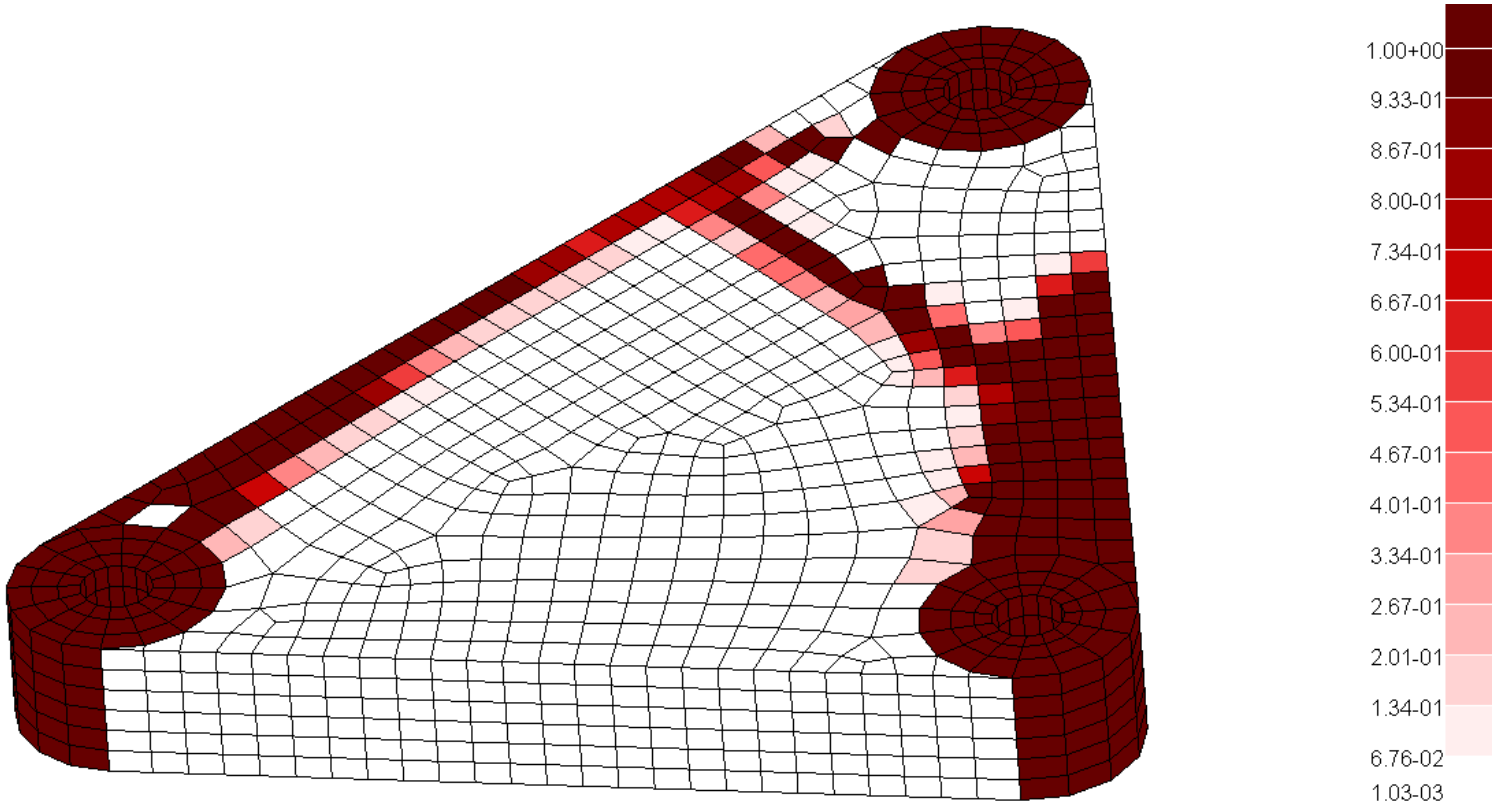
Total: 1.8

.1	.1	1.0
.1	.1	.4

3) Optimization
- FRMASS < .3
- Normalized Densities are varied

What are the design variables in Topology Optimization?

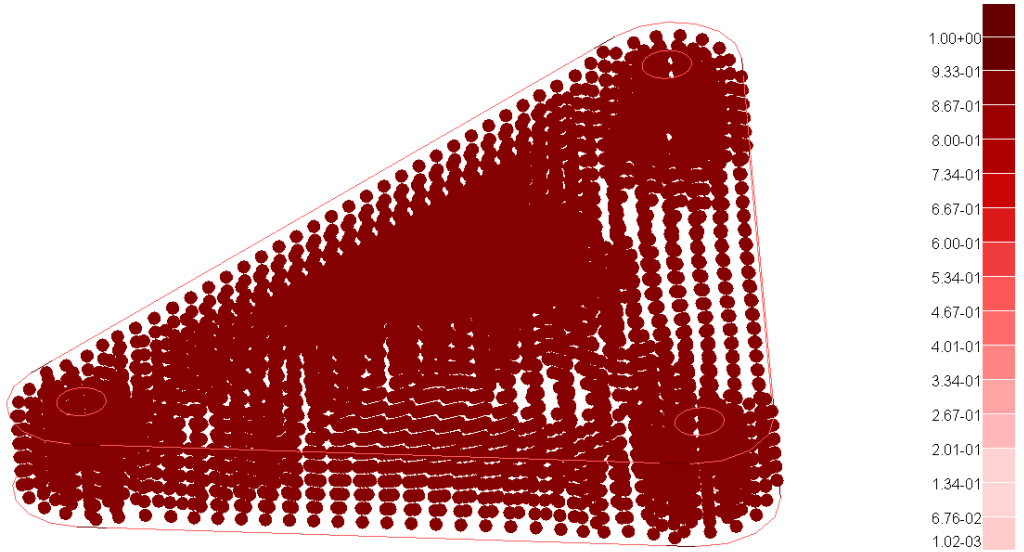
- Each element that is within a design region is given a design variable that represents a *normalized material density*
  - 0 - Normalized density values close to 0 are not critical to the design
  - 1 - Normalized density values close to 1 are critical to the design



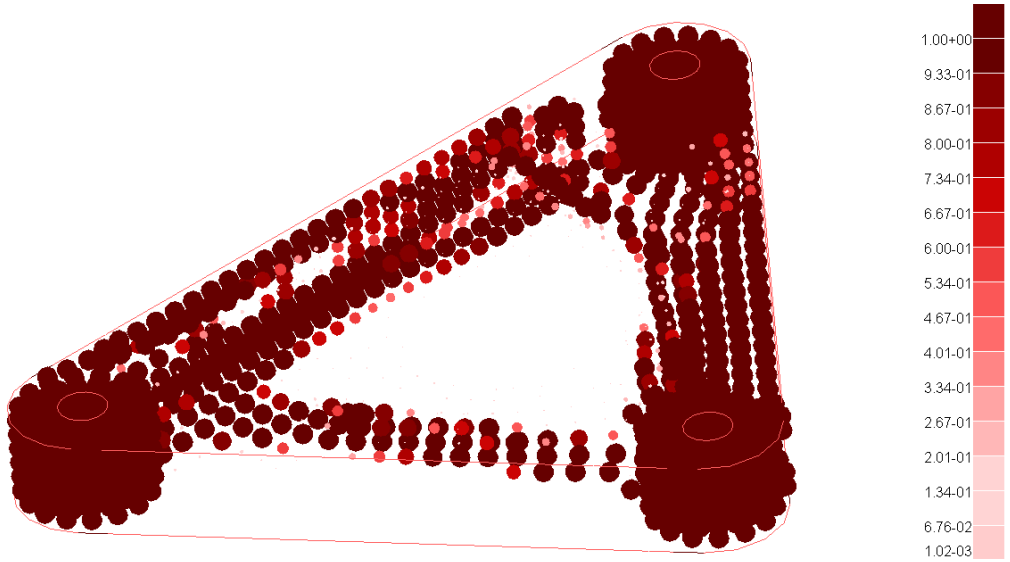
The final values of design variables or normalized densities are plotted for each element.

What are the design variables in Topology Optimization?

- Each element that is within a design region is given a design variable that represents a *normalized material density*
  - 0 - Normalized density values close to 0 are not critical to the design
  - 1 - Normalized density values close to 1 are critical to the design



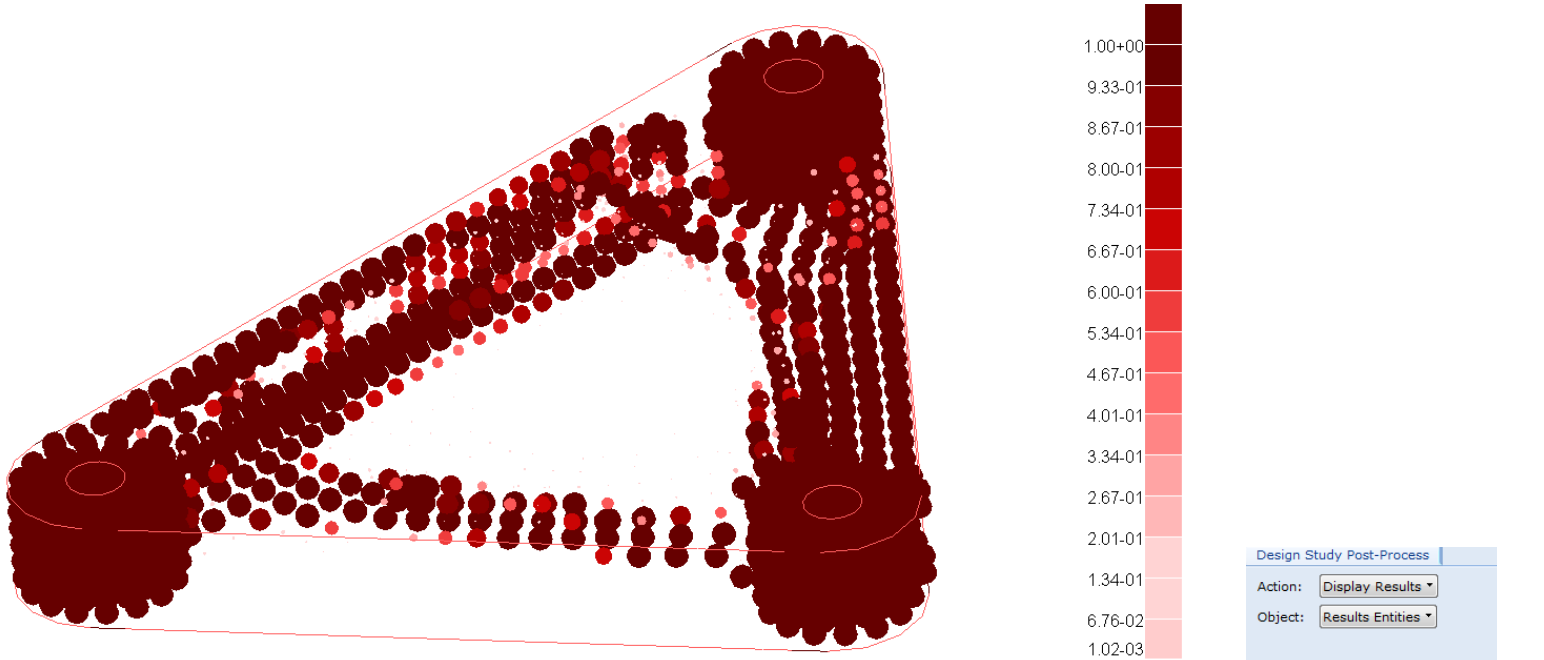
For the initial design, the normalized densities start at a value of .9.



At the end of the optimization, each element has a different normalized density.

How can non-critical elements be removed from the design?

- Use the threshold to suppress non-critical elements
- The threshold means: *'Keep every element that has a normalized density greater than the threshold'*
- Recall from before:
  - 0 - Normalized density values close to 0 are not critical to the design
  - 1 - Normalized density values close to 1 are critical to the design



The normalized densities are plotted for each element. Note that all the elements are present.